Comment on "Tensor force in doubly odd deformed nuclei"

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An article by Covello, Gargano and Itaco [Phys. Rev. C **56**, 3092 (1997)] tries to find evidence for the important role of the residual tensor force between the valence proton and neutron in doubly odd deformed nuclei. It is shown that observable effects discussed by these authors do not fully justify their rather strong conclusions.

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Recently, the role of the effective proton–neutron (p–n) interaction with particular attention focused on the tensor force operating between the unpaired proton and neutron in odd–odd deformed nuclei was studied by Covello et al. [1]. Their results obtained for ^{176}Lu were interpreted as evidence for the originally proposed central+tensor force [3] which "may be profitably used for a systematic study of doubly odd deformed nuclei in the rare–earth region" [1]. In this Comment we critically analyze rather strong conclusions articulated by Covello et al. [1] and also by Itaco et al. [2]. Our method and results [4], that was also questioned in Ref. [1], will be defended elsewhere.

In their study, Covello et al. [1] carried out calculations of the spectrum of the first K$^{\pi}$=0$^-$ band built upon the $\{\frac{7}{2}$+[404] $\frac{7}{2}$–[514]$\}$ intrinsic configuration in ^{176}Lu and found out that very good agreement with experiment is achieved only if the central+tensor forces with the Gaussian radial shape are taken into account when the Newby (N) shift in this band is estimated. They stated that its empirical value is exactly reproduced when the p–n parameters as recommended by Boisson et al. [3] are used. Then, not surprisingly, also the whole rotational band is very well reproduced since there is no evidence of mixing with other bands. But, it is interesting to note that this N shift was not satisfactorily calculated in Ref. [3] even if the tensor terms of the Gaussian force were set active, see Table I. On the other hand, our finite–range values of this N shift the estimates of which are based on different empirical sets of the p–n parameters [4] agree well with experiment as shown in Table I. Consequently, also our empirical sets of the p–n parameters with not well determined tensor strengths yield a consistent explanation of the spectrum of the lowest K$^{\pi}$=0$^-$ band. Unfortunately, the authors of Ref. [1] did not provide any comparison of their theoretical B$_N$ values in this band with our results [4].

In our opinion, there is more serious difficulty concerning the predictive power of the experimental spectrum of the first K$^{\pi}$=0$^-$ rotational band in ^{176}Lu. Since the relevant N shift is of the central type (NC shift [3]), it is not expected to possess significant tensor contributions [3]. In our analysis the results of which are given in Table I, the central terms of the Gaussian force are sufficient to predict its reasonable theoretical value even though small tensor contributions with the right signs are calculated. Thus, this particular example have a little to do with the importance of the tensor–force effects.

It is worth noting that the N shift measured in the K$^{\pi}$=0$^+$ $\{\frac{7}{2}$+[404] $\frac{7}{2}$+[633]$\}$ band in ^{174}Lu and also in ^{170,172}Lu and ^{176}Ta [4] which is of the tensor type (NT shift [3]) gives a better picture of the tensor–force effects. Although the strengths of the tensor forces are not well determined in our experimental set of the N shifts [4], their effect is well visible in Table I where different values of this N shift are collected. (Notice that our theoretical B$_N$ values are very different from those calculated in Ref. [2].) In our calculations, similarly as in the previous example, the finite–range tensor forces operate in the right direction. Their contributions are, however, more significant since the central forces alone do not provide an acceptable B$_N$ value. Nonetheless, the tensor–force effects are rather small in order that one can deduce a definite conclusion.

The second point we want to discuss is the role of irregularities which are known to be present in rotational bands in ^{176}Lu. In Ref. [1] and a subsequent preprint [2], the authors analyzed an odd–even staggering observed experimentally in the two lowest K$^{\pi}$=1$^+$ rotational bands built upon the $\{\frac{9}{2}$–[514] $\frac{7}{2}$–[514]$\}$ and $\{\frac{7}{2}$+[404] $\frac{9}{2}$+[624]$\}$ configurations, respectively. They suggested that this rather large staggering may be caused by direct Coriolis coupling with Newby–shifted K$^{\pi}$=0$^+$ bands assigned as $\{\frac{7}{2}$–[523] $\frac{7}{2}$–[514]$\}$ and $\{\frac{7}{2}$+[404] $\frac{7}{2}$+[633]$\}$, respectively. But these effects are small; typically 5–15 % admixtures were reported in Refs. [1,2]. In the former case, the main trends were reproduced with the central+tensor Gaussian force [1]. The latter effect, that is equally well developed in the experimental spectrum, failed to be described satisfactorily. The best picture, even if it is hardly acceptable, was obtained with the same type of the residual p–n force [2]. All these results were then interpreted as "clear evidence of the importance of the tensor–force effects" [1], see also Ref. [2].

TABLE I. Newby shifts, B_N, in the three discussed K^π=$0^\pm$ bands in ^{174,176}Lu. Their types are given in the third column. The experimental and theoretical central+tensor (CT) values obtained by Boisson et al. [3] are written in the forth and fifth columns, respectively. The theoretical values obtained by Covello et al. [1] and Itaco et al. [2] with the δ force (δ), the central (C) and central+tensor (CT) Gaussian force are listed in the sixth, seventh and eighth columns, respectively. Our empirical and theoretical values of these N shifts, the latter obtained in different fits [4] with the δ potential (δ), the central (G) and central+tensor (G_T) Gaussian force, and with the intrinsic spin polarization effects (fits δ_P, G_P and G_{TP}), are given in the following seven columns.

			B_N [keV]											
			Ref. [3]		Refs. [1,2]			Present values						
Nucleus	$\{\Omega\pi[\mathrm{Nn}_z\Lambda]_p\ \ \Omega\pi[\mathrm{Nn}_z\Lambda]_n\}$	Type	Exp	CT	δ	C	CT	Exp	δ	δ_P	G	G_T	G_P	G_{TP}
^{176}Lu	$\{\frac{7}{2}+[404]\ \frac{7}{2}-[514]\}$	NC	69	35	–	–	70	69.2(0.6)	12.1	32.9	78.2	64.8	73.5	64.6
^{174}Lu	$\{\frac{7}{2}+[404]\ \frac{7}{2}+[633]\}$	NT	-35	-29	6	1	-26	-40.0(3.2)	-27.1	-43.2	-28.2	-35.7	-32.5	-36.5
^{176}Lu	$\{\frac{7}{2}-[523]\ \frac{7}{2}-[514]\}$	NT	–	–	–	–	–	-155.5(1.2)	-28.7	4.0	-22.6	-40.7	-18.7	-35.4

TABLE II. Gallagher-Moszkowski splitting energies, ΔE_{GM}, for the two discussed intrinsic configurations with K^π=1^+ and 8^+ in ^{176}Lu. The experimental and theoretical GM values given by other authors [1,3] as well as the present values based on the revised interpretation [7] are summarized. Our present experimental values of the GM splitting energies written in the ninth column are corrected for the ΔK=0 interaction, for more detail see text.

		ΔE_{GM} [keV]										
		Ref. [3]			Ref. [1]		Present values					
Nucleus	$\{\Omega\pi[\mathrm{Nn}_z\Lambda]_p\ \ \Omega\pi[\mathrm{Nn}_z\Lambda]_n\}$	Exp	C	CPTL	Exp	CT	Exp	Exp ΔK=0	G	G_T	G_P	G_{TP}
^{176}Lu	$\{\frac{9}{2}-[514]\ \frac{7}{2}-[514]\}$	–	-239	-141	-219	-154	-220.3(5.1)	-223.9(5.2)	-184.3	-200.8	-168.3	-178.4
^{176}Lu	$\{\frac{7}{2}+[404]\ \frac{9}{2}+[624]\}$	–	-130	-107	-12	-90	-15.4(3.2)	-51.8(3.2)	-159.9	-132.4	-150.1	-117.7

In our previous study [4], we have assumed an old interpretation [5,6] for the two lowest K^π=1^+ rotational bands with the band heads at 194 keV and 338 keV, respectively. The revised interpretation of these bands given by Klay et al. [7] yields theoretical values of the Gallagher–Moszkowski (GM) splitting energies calculated with our sets of the p–n parameters which are in even better agreement with experiment than our previous results [4], see Table II.

We have carried out preliminary calculations of the spectrum of ^{176}Lu assuming 42 low–lying rotational bands of positive parities and including the Coriolis interaction, intrinsic rotational contributions, recoil terms, diagonal terms of the residual p–n interaction, and also non–diagonal p–n mixing (ΔK=0 interaction); the latter was not considered in Refs. [1,2]. We have used the same mean–field parameters of the Nilsson potential as in Ref. [4]. The G_T sets of the p–n parameters have been adopted from the same study.

The most striking feature of our calculations is that there is strong ΔK=0 mixing between both K^π=1^+ rotational bands as well as between their K^π=8^+ GM partners with non–diagonal matrix elements $|< V_{pn} >| \approx 50 - 60$ keV. When included, this interaction, for example, affects significantly empirical values of the GM splitting energies. This is demonstrated in Table II where corrected empirical values, that are obtained assuming the G_T(GM) set [4] of the p–n parameters for the ΔK=0 interaction, are written in the ninth column. This finding suggests that the odd–even staggering can be transferred from one band to the other; such a picture was not confirmed in Refs. [1,2]. Further, since the K^π=0^+ $\{\frac{7}{2}-[523]\ \frac{7}{2}-[514]\}$ band is expected to lie very high in energy (its band head was tentatively placed at 1057 keV [6]), its influence on the low–lying K^π=1^+ band is found to be smaller in our calculations than in those performed in Ref. [1]. In particular, the odd–even staggering that is discussed in Ref. [1], is equally well explained in our calculations only if very strong Coriolis mixing with the relevant K^π=0^+ band exists. It holds if our theoretical G_T value of the corresponding N shift is taken from Table I. Let us note that also in this case the tensor–force effects are not negligible. However, due to tentative assignment of this K^π=0^+ band [6], an extremely large absolute empirical B_N value has to be regarded as very uncertain [4] and can hardly be compared with our predictions. Unfortunately, the authors of Refs. [1,2] did not provide any theoretical value of this quantity. On the other hand, the odd–even staggering in the K^π=1^+ $\{\frac{7}{2}+[404]\ \frac{9}{2}+[624]\}$ band, that is badly described in Ref. [2], is very well reproduced in our calculations based on our well determined value of the N shift in the K^π=0^+ $\{\frac{7}{2}+[404]\ \frac{7}{2}+[633]\}$ band in ^{174}Lu, see Table I. Moreover, we have found that, due to the ΔK=0 interaction, the latter staggering is partially transformed into the $K^{\pi}=1^{+}$ band lying lower in energy. Nevertheless, a better analysis of this effect is required.

In conclusion, we would like to stress that our previous statement [4] that the p–n parameters of the tensor forces are not well determined in our set of presently known N shifts does not imply that their role should be negligible. Here, we are forced to infer that, although probably right in principle, the conclusions concerning the importance of the tensor–force effects drawn in Refs. [1,2] are not sufficiently supported. The reason is that a particular example (the lowest $K^{\pi}=0^{-}$ band in ^{176}Lu) cannot indicate general features which are known to be extremely subtle. Nearly the same picture is obtained when the space–exchange and spin–spin space–exchange forces [4] for the description of the N shifts are assumed to be the most important. In such a way, the spectrum of the lowest $K^{\pi}=0^{-}$ band does not provide any argument against our previous conclusions [4].

It should be finally pointed out that there remains a place for a different explanation of the observed odd–even staggering in the low–lying $K^{\pi}=1^{+}$ bands discussed in Refs. [1,2]. The crucial point for its understanding lies in a proper estimate of non–diagonal mixing which is caused by the Coriolis coupling, as correctly suggested in Refs. [1,2], but also by the $\Delta K=0$ interaction. Thus, we conclude that the odd-even staggering and its theoretical description including the tensor terms does not directly imply that "only this force is able to reproduce a sizable N shift" [1,2] for both $K^{\pi}=0^{+}$ bands under consideration.

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